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Technical Evaluation Report on Fluid Dynamics Panel Specialists' Meeting on Wall Interference in Wind Tunnels

NORTH ATLANTIC TREATY ORGANIZATION

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Advisory Report No.190

TECHNICAL EVALUATION REPORT

on

FLUID DYNAMICS PANEL SPECIALISTS' MEETING

on

WALL INTERFERENCE IN WIND TUNNELS

by

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WALL INTERFERENCE IN WIND TUNNELS

TECHNICAL EVALUATION REPORT

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1. INTRODUCTION

On 19-20 May 1982, The AGARD Fluid Dynamics Panel, chaired by M. l'Ing. en Chef B. Monnerie, held its 50th meeting - a specialists meeting on Wall Interference in Wind Tunnels - at Church House in Westminster, London. The meeting was organized by a program committee composed of Dr. M.L. Laster (Chairman), Ir. J.P. Hartzuiker, Professor Dr. Ing. B. Laschka, Mr. L.H. Ohman, Professor E. Mattioli, Professor A.D. Young, and M. l'Ing. C. Dujarric.

The Fluid Dynamics Panel has been concerned for some years with stimulating activity to understand and quantify the effects of wind tunnel wall interference upon measured aerodynamic phenomena. Many research endeavors have been undertaken to learn how to either analytically correct wind tunnel data or to reduce the wall induced interference to a negligible magnitude by manipulation of the test section boundary. Successful efforts to routinely correct data have been largely limited to solid wall, low speed situations, although recent ideas provide hope that corrections may be applied in any tunnel and for high speeds. The invention of ventilated wall tunnels did much to reduce the tunnel boundary induced interferences, but not to negligible magnitudes especially at transonic conditions. The advent of the adaptive wall concept, in which the tunnel boundary is actively controlled, promises to finally provide a test environment with negligible wall interference even at transonic speeds. The primary purpose of the specialists meeting was "to review and assess the current status of wall interference correction methods and adaptive wall research" in three sessions: Solid Wall Wind Tunnels, chaired by A.D. Young; Ventilated Wall Wind Tunnels, chaired by L.H. Ohman; Adaptive Wall Wind Tunnels chaired by W.R. Sears. Sixteen papers and the summary discussion have been published in the Conference Proceedings, AGARD CP335, September 1982. Approximately 130 people attended the meeting.

2. DISCUSSION

2.1. Solid Wall Wind Tunnels

It can be shown that regardless of the tunnel wall configuration there is enough information contained in any two independent flow field quantities measured near the tunnel boundary to allow the computation of the wall interference flow field at the model position without the necessity of mathematically representing the test article. The independent variables may be static pressure, flow angle, axial velocity, normal velocity, etc. The solid wall wind tunnel has one definite advantage in this regard since one boundary condition, velocity normal to the wall equals zero, can be specified exactly. Ashill and Weeks have used this fact to derive the equations to compute the axial and upwash interference velocities at the model in a solid wall tunnel from measured wall pressures. For the 2-D tunnel, the assumption is made that the sidewall effects can be ignored because it is doubted that the complication of measuring the sidewall boundary conditions and added complexity of the calculations justifies the potential results. While this assumption is more plausible the larger the tunnel width to model chord ratio, for most test applications it is well documented that the sidewall does produce a significant influence on the data. Inclusion of the sidewall conditions in the theory would allow the effects of the vorticity caused by any non-two-dimensionality of the flow to be included automatically as part of the calculation. Application of the theory by Ashill and Weeks to a 14% thick airfoil (chord to tunnel height ratio of 0.26) revealed some conditions in which the interference gradients were large enough to be deemed not "correctable in the strict sense". For the instance cited in the paper ($M_\infty = 0.73$, $0.3 < C_N < 0.7$), the Mach number gradient along the chord was about 0.0008 which could probably be ignored; however, the upwash gradient was significant, varying almost 0.4-deg along the chord at the high C_N condition. Thus, while not correctable except by an equivalent camber change, at least the investigators know how bad things really are - a worthwhile piece of information in itself as the authors properly note. Application of the method to data from the CERT T-2 Adaptive Wall Tunnel (a solid compliant wall facility) indicated small residual corrections at the adapted conditions at M = 0.73 and non negligible residual corrections at a condition in which the sonic line had reached the wall. For the latter instance, one could legimately argue the merits of both the theory and the adaptive process, neither one may be strictly applicable to that situation.

Holt and Hunt[2] propose the use of a panel method to predict subsonic wall interfèrence effects in both two and three dimensions. Complex models and the tunnel wall geometry are represented by discrete rectilinear surface singularities. In principle, a ventilated wall may also be represented by specifying a proper transpiration distribution at the wall panels. Programs exist which utilize the homogeneous boundary assumption to simplify the boundary specifications. The calculations are solutions to the Laplace equations and include relaxed vortex wakes where appropriate. The wall interference is determined by subtracting a solution with the model in the tunnel from a solution of the model in free air. Examples cited show the inadequacy of classical correction methods using simple model representations in all but the simplest instances and reaffirm the necessity of considering the interference distribution over a model in determining the equivalent free air conditions of a model test. In a two-dimensional example, it is shown that, for a flapped airfoil, data taken with a fixed flap angle in the tunnel, when corrected, are equivalent to free air data with varying flap angle; thus requiring an interpolation of several tunnel runs to obtain the desired information. Three-dimensional examples indicate the power of the geometrically versatile panel method in treating wing/body/ canard configurations. For such a configuration, it is essential to not specify the wake position in both the tunnel and free-air calculation even though one can specify a wake trajectory which "looks reasonable". In a wing alone example, the effect of a relaxed wake position is to reduce the calculated lift by about 5% relative to the specified wake trajectory usually employed. In addition, the spanwise load distribution is effected; the tip region being much more sensitive than the root. With a canard and wing configuration, the canard (represented as a simple horseshoe vortex in the example) experiences an interference which is sufficiently uniform to be approximated as a classical upwash change. However, the wing loading is effected not only by the upwash effects but also by a tunnel induced change in the canard wake position which is not negligible; particularly if the incidence is high enough to be in vortex bursting regime. Such interference is not correctable by classical means, but the panel method can be used to indicate the magnitude and location of the tunnel constraint effects. While the paper points out other applications of the panel method, it fails to recognize the necessity of not only representing the detailed model configuration in the tunnel but also its support system (see Section 2.2. paper 11). Because of the forward effect of the support system blockage on the flow field at the position of the model it must also be represented in the calculation to properly assess the wall interference. In doing so one also automatically compensates for the support system interference on the model data. Of course, such a representation does require larger computer resources.

The influence of the sidewall boundary layer on airfoil data obtained in a solid wall tunnel was the subject of Barnwell and Sewall[3]. For a two-dimensional tunnel in which the height is reasonably large compared to the width and the width is sufficiently small for the flow on each sidewall to be influenced by the boundary layer on the opposite wall, it is shown that the influence of the sidewall boundary layer on the airfoil flow field is similar to compressibility effects. The similarity is used to derive a modified Prandtl-Glauret rule for subsonic flow and a modified von Karman rule for transonic flow. Experimental verification of the theory shows reasonably good results for subsonic flow and improved correlations as Mach number increases toward unity. The theory is an excellent start, greatly improving data correlations and demonstrating the importance of compensating for the sidewall boundary layer in 2-D tunnels. Improvements may be gained, particularly at the high Mach numbers, by considering the three-dimensionality of the sidewall boundary layer and the influence of the model pressure gradient on the boundary-layer properties which are contained in the formulation.

Wall interference is, of course, not the only factor which has an adverse influence on wind tunnel data. For many years many data discrepancies and otherwise unexplained anomalies have been blamed on Reynolds number mismatches. However, recent careful investigations of data anomalies have indicated that Reynolds number does indeed effect the data, but the causes of those effects are associated more with pseudo-Reynolds number influence on the wind tunnel flow properties than with the phenomena being investigated. In paper 4, Aulehla and Eberle present three examples which show that what could be assumed to be a strong Reynolds effect on shock location is more probably caused by changes in the solid-tunnel-wall boundary layer effecting the tunnel calibration. The effects are manifested in two ways, a change in free-stream Mach number and a change in the free-stream pressure gradient (bouyancy) as a function of total pressure. When these influences are taken into account, the effect of Reynolds number on the model data presented largely disappears. The authors suggest, and it can be shown from several viewpoints, that for tests of afterbody configurations and tests in which the terminal shock location is a strong influence on the phenomena being investigated, accuracies in free-stream Mach number and pressure coefficient of 0.0005 and 0.001, respectively, are required. Such accuracies are only achievable if the effect of total pressure on the test section calibration (whether solid or ventilated) are considered. Nothing can be assumed. To achieve such accuracies every possible influence must be evaluated.

The GARTEur Action Group on Two-Dimensional Transonic Testing Methods has embarked on a study of testing the CAST 7 airfoil in 7 European tunnels to determine how well the data correlate and perhaps the reasons for data anomalies. A progress report of this activity is presented in paper 5. As one might expect, there is a large variation in the data before wall interference corrections were applied. After correlation, using methods unique to each facility (no corrections in two ventilated tunnels), the data differences were considerably reduced (± 0.2-deg in incidence, ± 0.003 in Mach number). Remaining differences are attributed to other factors - sidewall boundary-layer effects, uncertainty of correction calculations, uncertainty of tunnel calibration, etc. The variation of the various aerodynamic coefficients with Reynolds number (varied from 1.3 to 11 x 10^6) derived from all the test data is reasonably consistent leading one to believe the variation is real. Yet it is not stated if all or any of the tunnels were calibrated as a function of total pressure, a potential which could influence the results. Compared with the results from the CERT-T2 tunnel operating in the adaptive mode which are taken as truth, data from the two ventilated tunnels need corrections in spite of the fact that the test section wall geometry was optimized by testing different size models of the same airfoil. Data from the Technical University - Berlin adaptive tunnel appear to suffer from three-dimensional effects caused by the sidewall boundary layer. There is a large difference in maximum lift coefficient (≈ 0.1) even after all corrections are applied. While the reason for the large $C_{L_{max}}$ discrepancies are not understood, one would expect they must be related to the state of the boundary layer across the whole span of the 2-D airfoil and probably along the tunnel sidewall as well. Well designed test series of the type described are especially useful to confirm the state-of-the-art test techniques and identify areas in which further understanding is needed. The tests would be even more useful if they could be repeated to test hypotheses to explain the anomalies which still exist.

2.2. Ventilated Wall Wind Tunnels

Sune Berndt in his paper[6] presents a progress report on FFA's work to understand and thereby predict the characteristics of slotted walls. His basic thesis is that, by proper shaping of test section slots, wall interference may be eliminated. Data examples are presented indicating the effect of slot shape and slot depth on slot characteristics. In addition, typical results are shown from an inviscid, transonic small perturbation theory which uses an individualized slot flow model to yield, for a given slot depth, an optimum slot shape to minimize interference. The theory has yet to be experimentally verified.

One of the primary difficulties when analytically computing the boundary condition for a porous wall wind tunnel has been the proper characterization of the wall/boundary-layer interaction. In a solid wall tunnel, classical boundary-layer theory is adequate for estimating boundary-layer growth and its effects can be somewhat negated by slight wall divergence. (The problem of Reynolds number effects discussed in Section 2.1. still remains). For a porous wall tunnel, however, the boundary-layer development is complicated by both inflow and outflow induced by the model imposed pressure gradient. Furthermore, the wall crossflow resistance is a strong function of the local boundary layer properties which cause a highly non-linear wall characteristic. Additional insight into this problem is contained in the paper by Y.Y. Chan[7]. Experiments were conducted in the 2-D facility with 20.5%-open normal hole upper and lower wall and sidewalls with a permeable section in the vicinity of the airfoil through which boundary layer suction could be applied. Theory and experimental data are combined to yield a reasonable picture of the highly non-linear wall characteristics along the porous walls which is also a function of Mach number and model incidence. Empirical correlations, valid only for the NAE tunnel, are derived which allow the spatially variable wall characteristics to be calculated from the pressure distribution measured just outside the boundary layer. Work should continue to demonstrate that the wall characteristic thus determined can be used to calculate the correct wall interference field. An added complication, however, may be caused by the sidewall boundary layer which Chan shows to be highly three-dimensional, particularly when the tunnel is operated without suction. The three-dimensionality is caused by the model induced pressure field. Applying sidewall suction in the manner of the described experiment does lessen the three-dimensionality of the sidewall boundary layer. Nevertheless, it appears to this reviewer that the three-dimensional aspects of wall interference must be considered before the "right" answer (correction) can be obtained for two-dimensional airfoil tests.

For situations in which homogeneous boundary conditions can be assumed, the vortex lattice method can be a powerful tool for computing wall interference. Perhaps the primary advantage of the method is that complicated model geometries can be represented rather easily; having a computer large enough and fast enough to solve problems being the primary restriction. The major problem in using the technique is the specification of an appropriate value of the homogeneous boundary condition for ventilated tunnels. The correct value must generally be determined with a proper experimental program. Paper 8 discusses some results from a vortex lattice program. The slotted wall geometry factor selected, $K = f/\pi \ln [\sin (\pi a/2f)]$ has been shown not to agree well with experimental data. However, this fact does not negate the results presented, but would cause difficulties if the program's results were to be applied to experimental data. The equations in Ref. 8 are formulated so that viscous effects in a slotted wall tunnel representation may be approximated by including a value for the porosity factor as has been done by other investigators. However, solutions presented with the porosity factor representing an open jet and simultaneously the slot parameter representing a nearly closed tunnel have no physical equivalent. The paper also describes an experimental program, but a correlation with the theory has not yet been made.

Calculations of wall interference in the past have in essence been predictive techniques, relying on derived boundary conditions and reasonably simple model representations; vortex lattice and panel methods being a recent exception. However, techniques are evolving out of the methods used in the adaptive wall work which do not require any explicit information about the wall characteristics or even the model. These methods are properly termed wall interference assessment techniques because they all require some measurement to be taken during the tests. Smith[9] summarizes the three basic types which have been developed for 2-D flows and are currently in the refinement and verification stage. Using his nomenclature, the "Caughy" type requires the measurement of two flow variables near the tunnel boundary from which the interference distribution may be determined. No information about the model is required. The "Caughy" methods Smith describes are limited to linearized subsonic flow because they are formulated from the Laplace equations. However, there is no fundamental reason why the transonic equations cannot be used with a numerical rather than analytical formulation. A second type termed the "Schwartz" type by Smith requires the measurement of one boundary variable and a reasonably accurate analytical representation of the model. The third, "matching type" requires one boundary variable and the model pressure distribution as well. The model pressures are used to derive the accurate model representation. All three methods are applicable to any 2-D tunnel provided techniques can be worked out to adequately measure the required boundary conditions. The same principles can be applied to 3-D flows with Green's theorem performing a similar function as the Cauchy integral does in the 2-D formulation. Smith cites several practical problems which must be solved to make any of the formulations a routine part of testing. He presents the results from five formulations by different investigators calculating the same problem. The Mach number corrections agree to within 0.002 and the incidence correction to within 0.1 deg. While this is encouraging, it hardly constitutes verification which can only come by comparisons to wall interference-free data obtained from very precisely controlled experiments.

Mokry[10] presents a derivation of a "Swartz" type method for wall interference assessment in three-dimensional test sections. The one variable boundary condition is obtained from static pressures measured on rails attached to the walls at the 0,90, 180, and 270-deg positions. The circumferential distribution of the boundary condition is interpolated by a Fourier expansion of the axisymmetric functions. The model is assumed small with respect to the tunnel and is represented by a horseshoe vortex, a source and a doublet whose strengths are derived from model forces and geometry. The mathematical formulation is verified by comparison with a proven theoretical solution. Two practical examples are calculated which result in very small corrections except in one incident in which it appears something is not right with the experiment. While not to detract from the usefulness of this paper in the evolutionary development of interference assessment techniques. The method should be compared with corrections derived from wall interference-free results.

For quite some time ONERA has been calculating wall corrections for tests in their tunnels using methods derived from classical theory. In paper 11 Vaucheret discusses the evolution of that effort to predict a more realistic value of the correction factors. Vaucheret states that there is no point in making corrections if they cannot be verified. ONERA has pursued the assessment of the correctness of the interference predictions using test data from the same model in different size wind tunnels or at different height locations in the same tunnel. Their experience has shown that classical model representations are generally inadequate even for computing the interference in solid wall tunnels. However, for blockage corrections, if the models including the support stings are represented by several doublets (up to 35 or more) and several vortices for upwash corrections, adequate corrections can be computed to rather high Mach numbers. In addition, for ventilated tunnels empirically derived homogeneous boundary conditions can be used successfully for some conditions. Three points should be emphasized. First, the contribution of the model support to the interference over the model is large. Therefore, the support system must be included in the calculations. Second, even at low speeds the corrections are very non-linear over the model length and span. Therefore, the application of the corrections to the data can be quite complicated. If the interference velocities are large enough to significantly displace the terminal shock location in transonic flow, the data are not correctable, hence the need for adaptive walls. Third, for ventilated wall tunnels the range of applicability (in both test conditions and model configurations) of the empirically derived homogeneous boundary condition must be established. The primary advantage of using wall interference prediction methods derived from classical theory is that such methods require relatively small computer resources. However, in order to use them with confidence, it is essential that the limitations be established as ONERA is doing.

2.3. Adaptive Wall Wind Tunnels

Active development of adaptive wall wind tunnels has been progressing for the past decade. Presently several organizations are working on several concepts to develop a system which fulfills the adaptive wall promise - a wall interference-free testing environment. Papers presented in this portion of the program discussed progress in development of three basic wall concepts (a) solid, compliant walls, (b) slotted walls with variable, distributed suction, and (c) porous walls with variable, distributed porosity. Concept demonstrations which have been completed to date are largely concerned with two-dimensional testing. However, much of the groundwork for three-dimensional application has been completed and three experimental efforts are just getting underway.

Work with solid compliant walls is being conducted at the Berlin Technical University[13], ONERA-CERT[14], and University of Southampton[15] and is planned at the DFVLR[13]. Each of these demonstration wind tunnels use wall pressure measurement as the independent variable in the exterior calculation and wall angle distribution as the convergent variable. Two-dimensional experiments have been done with both the NACA-0012 and the CAST 7 airfoils. The CAST 7 is a rather severe test for an adaptive wall tunnel since, being a supercritical design, it is sensitive to small changes in Mach number and incidence near its design point. While 2-D tests with the NACA-0012 have verified the compliant wall concept up to the conditions at which the supercritical zone reaches the wall[13,14,15], the theory in use for the exterior calculations use the linear Laplace equations which does not allow the calculations to be done for conditions at which the terminal shock would penetrate the wall. Thus, until the exterior calculation can be done with the transonic equations these demonstrations are at a standstill.Experiments with the CAST 7 even at conditions below supercriticality at the wall have been plagued with experimental problems. The CAST 7 interference-free data are suspect because of anomalies in the large wind tunnel in which the data were obtained. In addition, the sidewall boundary layer and model transition location effects cause difficulties in the adaptive tunnel, particularly with a supercritical airfoil. These problems are a very graphic demonstration that an adaptive wall tunnel will not magically solve all of the other problems which can cause anomalous experimental results - whether 2D or 3D.

The first 3-D experiments have been done by Ganzer[13] at Mach number 0.699 using the ONERA C-5 body of revolution configuration. The experiments were conducted as a prelude to testing a lifting configuration. The C-5 data in the 3D-adaptive tunnel do not show the spectacular changes as obtained with the 2-D experiments because the interference is lower in the 3-D case. In addition, when compared to interference-free data obtained on a larger C-5 model the adaptive wall model appears to experience regions of separation not found in the larger model data. Additional work is planned to resolve the difficulties.

The use of adaptive wall techniques in facilities with short run times poses difficult problems in rapid boundary condition adjustment to obtain a converged solution during a single run. Of course, rapid convergence is also of interest in continuous facilities to decrease operating cost. Archambaud and Chevallier[14] describe a rapid computational technique which allows a complete iteration in about 10 seconds. The mathematical formulation is written in terms of the potential function with the model represented by singularities whose strengths are based upon model measurements. Thus, residual effects of misadjustments also can be computed for test conditions at which linear theory is applicable. Representative experimental results are presented from the compliant solid wall CERT-T2 wind tunnel with a two-dimensional CAST 7 airfoil. Interesting examples are shown in which converged solutions are obtained with the model on the centerline and 20% of the tunnel height below the centerline. The model pressures converge to the same values. In addition, it is shown that small angle-of-attack changes can be simulated by rotation of the walls about a nozzle exit hinge line and the effect of bouyancy gradients can be induced by diverging or converging the walls. Unfortunately, none of the experimental wing pressure data are compared to interference-free results.

Three-dimensional experiments at Southampton[15] in their modified 2-D tunnel (straight vertical, compliant horizontal walls) also demonstrate the lower magnitude of perturbations at the wall with 3-D models. With straight walls and the 3-D model configuration, the tunnel chokes at the sting support at Mach number 0.61. However, in the adaptive mode there is ample wall movement to obtain $M_\infty = .94$ although there is no interference-free data for this condition. Nevertheless, the wall pressure signatures have much smaller variations than the 2-D situation. As a consequence, wall movements based on the 2-D strategy were too small and showed no apparent effect on the model forces and moments. Model size limitations in 3-D tunnels will probably be determined by span considerations. Thus, as Wolf, et al.[15] points out, the instrumentation and adaptive strategy will probably be much different in the 2-D and 3-D tunnels.

The adaptive wall concept being pursued by NASA Ames[16] consists of a solid-vertical-wall, slotted-horizontal-wall tunnel with spatial wall control being provided by several separately controllable plena. The required boundary conditions are obtained by measuring the crossflow velocity component on two surfaces with a traversing laser velocimeter. Two-dimensional experiments with this configuration converged well when conditions at the boundary surfaces were subsonic, however because of the linear theory used convergence was not obtained when the flow was supersonic at these surfaces. Three-dimensional experiments are being carried out with a sidewall mounted semispan model. Work so far at Mach number 0.6 and incidence to 6-deg has shown that interference has been reduced but the exterior solution underpredicted the velocity change required to converge and the maximum available suction in several plena was insufficient to produce the required pressure change. Work is continuing on a larger scale experimental apparatus.

Work at AEDC[17] is concentrating on porous walls in which boundary condition control is being obtained by segmented, variable-porosity walls surrounded by a constant pressure plenum chamber. The walls contain up to 24 segments, each individually controllable. Several wall concepts were explored in two-dimensions to arrive at the selected configuration. Both normal and streamwise velocity components at the boundary surface will be derived from pressure measurements along a static pipe. All of the work which has been done at AEDC preparatory to the 3-D demonstration experiments have clarified many aspects of the adaptive wall system requiring attention; in particular, the interface instrumentation, the wall configuration, and the automatic optimization procedure for adjusting the walls have been worked out. The exterior region will be computed from transonic small perturbation theory thereby removing that limitation of the other experiments described at this meeting. It only remains to conduct the experiments in order to learn the limitations of the concept and perfect improvements.

3. CONCLUSIONS AND RECOMMENDATIONS

For many years the fluid dynamic anomalies found in wind tunnel to wind tunnel or wind tunnel to flight data comparisons have been attributed to non-duplication of the Reynolds number - that much maligned dimensionless parameter. Papers at this meeting discussed at least three phenomena in wind tunnel tests which are in effect pseudo-Reynolds number effects. The first is tunnel calibration. There is ample evidence that, even in solid wall tunnels, the tunnel calibration is a weak but significant function of total pressure. Paper 4 correctly pointed to the tunnel wall boundary-layer effects manifested in displacement thickness changes with total pressure to be the real culprit. The second phenomena are changes in the sidewall boundary layer affecting the three-dimensionality of the flow during two-dimensional airfoil tests. The third, which greatly affects data from ventilated wind tunnels, is the variation in wall crossflow properties not only with total pressure but also with the model imposed pressure gradients along the walls. In this instance, the demon is a very complicated interaction between the local boundary layer and the ventilated wall which is still not well understood. One may argue that all these effects are related by Reynolds number and indeed they are; but, not in the usual sense of a mismatch between the model test and flight Reynolds number. They are tunnel and tunnel alone related problems having nothing to do with flight. With the contemporary demand for better accuracy and relevancy from wind tunnel data, the effect of all of the independent tunnel parameters on the test data need to be assessed. This will be a particular problem for the cryogenic facilities wherein the evil spirits will be working overtime.

In the present testing world, the use of classical wall interference prediction methods is generally not satisfactory. At the very minimum it is clear that in instances in which homogeneous boundary conditions are applicable, the model and its support system must have an adequate mathematical representation in the calculation. This may be accomplished by using multiple singularities, vortex lattice or panel representations. Which one is chosen is largely determined by computer resources and the programs available to the user. For simple models all three schemes, if properly applied, will provide similar results. However, the more versatile vortex lattice and panel methods will provide better spatial interference distributions particularly for complicated support systems.

The wall interference assessment techniques emerging from the adaptive wall work show promise to remove many of the impediments contained in classical prediction methods. The formulations which compute the interference flow field from two boundary condition variables are the most attractive because they do not rely on model data or a model representation. Thus, they are amenable to stadardization as far as a given tunnel is concerned - having a dedicated instrumentation system and mini-processor. By optimizing the system hardware and software, 3-D interference calculations in real time should be practical in a few years.

The adequacy of wall interference corrections has been hampered for years by implications of the small model assumption. The models, even though the blockages are normally reasonably small, are generally large enough to experience non-linear variations of the interference parameters along the model length and span even at low Mach number. The significant spatial interference variations, coupled with the demands for greater precision, make the application of "average" corrections to Mach number and incidence unsatisfactory in many instances. A new correction application strategy is needed which is independent of the methods by which the corrections are obtained. Although simpler methods may suffice, the ultimate solution for conventional tunnels may be to use wind tunnel data and measured boundary conditions to calibrate an appropriate CFD code which then extrapolates the data to free air. Such a capability would remove the problem that the wind tunnel model does not have (because of wall interference) shape similitude with the vehicle that flies or from the other viewpoint, the model is not tested in a uniform flow field. Once correction methods are available which overcome many of the unknowns in the classical theory, a systematic application of the methods needs to be undertaken to properly validate the correction procedure.

The evolvement of adaptable wall technology is proceeding. There is again ample evidence which indicates data at some test conditions are not correctable. An adaptive wall tunnel is the only way, other than flight test, to achieve the desired results. Of the three configuration contenders - solid, slotted or porous walls - all could prove to be viable, although instinctively one would suppose the ventilated concepts may have a wider Mach number applicability range. However at this stage, such a supposition is not assured. From an economic viewpoint a solid adaptable wall tunnel would be the most attractive. Whether it can be used satisfactorily in the high subsonic, low supersonic speed range remains to be seen. It is apparent that the adaptive strategy or at least the algorithm for a 2-D and 3-D tunnel will be different. It is encouraging that there has been no evidence in all of the work done to date that the adaptive concept will not work. Therefore, the aerospace community is looking forward to the completion of the research which promises to provide the means of removing one of the remaining large contributors to data uncertainty. However, it is not sufficient to demonstrate a particular concept will work. The range of applicability in both test conditions and model configurations must be established.

REFERENCES

[1]Ashill, P.R. and Weeks, D.J. "A Method for Determining Wall Interference Corrections in Solid-Wall Tunnels from Measurements of Static Pressure at the Walls".

[2]Holt, D.R. and Hunt, B. "The Use of Panel Methods for the Evaluation of Subsonic Wall Interference".

[3]Barnwell, R.W. and Sewall, W.G. "Similarity Rules for Effects of Sidewall Boundary Layer in Two-Dimensional Wind Tunnels".

[4]Aulehla, F. and Eberle A. "Reynolds Number Effects on Transonic Shock Location".

[5]Elsenaar, A. and Stanewsky, E. "A Report of a GARTEur Action Group on "Two-Dimensional Transonic Testing Methods".

[6]Berndt, S.B. "Flow Properties of Slotted-Wall Test Sections".

[7]Chan, Y.Y. "Wall Boundary Layer Effects in Transonic Wind Tunnels".

[8]Holst, H. "Three-Dimensional Wall Corrections for Ventilated Wind Tunnels".

[9]Smith, J. "Measured Boundary Conditions Methods for 2D Flow".

[10]Mokry, M. "Subsonic Wall Interference Corrections for Finite-Length Test Sections Using Boundary Pressure Measurements".

[11]Vaucheret, X. "Ameliorations des Calculs des Effets de Parois dans les Souffleries Industrielles de l'ONERA".

[12]Withdrawn

[13]Ganzer, U. "On the Use of Adaptive Walls for Transonic Wind Tunnel"

[14]Archambaud, J.P. and Chevallier, J.P. "Utilisation de Parois Adaptables pour les Essais en Courant Plan".

[15]Wolf, S.W.D., Cook, I.D. and Goodyer, M.J. "The Status of Two-and Three-Dimensional Testing in the University of Southampton Transonic Self-Streamlining Wind Tunnel".

[16]Schairer, E.T. and Mendoza, J.P. "Adaptive Wall Tunnel Research at Ames Research Center"

[17]Parker, Jr. R.L. and Erickson, J.C. "Development of a Three-Dimensional Adaptive Wall Test Section with Perforated Walls".

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14. Abstract

On 19–20 May 1982, the AGARD Fluid Dynamics Panel held a specialists meeting on Wall Interference in Wind Tunnels, in Westminster, London.

The Fluid Dynamics Panel has been concerned with stimulating activity to understand and quantify the effects of wind tunnel wall interference. Many research endeavours have been undertaken to learn how to correct wind tunnel data or to reduce the wall induced interference. Successful efforts have been largely limited to solid wall, low speed situations. The invention of ventilated wall tunnels did much to reduce the tunnel boundary induced interferences, the adaptive wall concept promises to finally provide a test environment with negligible wall interference. The primary purpose of the specialists meeting was "to review and assess the current status of wall interference correction methods and adaptive wall research" in three sessions: Solid Wall Wind Tunnels, Ventilated Wall Wind Tunnels, Adaptive Wall Wind Tunnels.

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